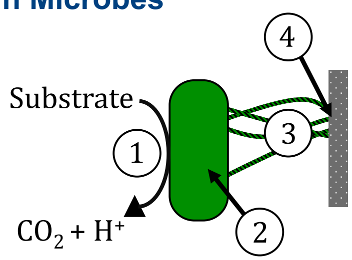
Wiring up Biology: Overcoming Transport Limitations in Microbial Energy Conversion

John Naviaux[1], Li Zhao[2], Jack Brouwer[2], Allon Hochbaum[1]
Departments of Mechanical and Aerospace Engineering[2], Chemical Engineering[1], University of California, Irvine

Introduction: Dirt Cheap Energy from Bacteria

- Bioelectrochemical devices are promising for **biofuels synthesis, wastewater treatment, energy production**, and **bioremediation.**
- Device efficiency is limited by **poor understanding of energy transport mechanisms.**
- Combining **engineered biofilm structures** with comprehensive **charge transport models and simulations** will drastically improve device efficiency.

Kinetics of Electron Transport in Microbes



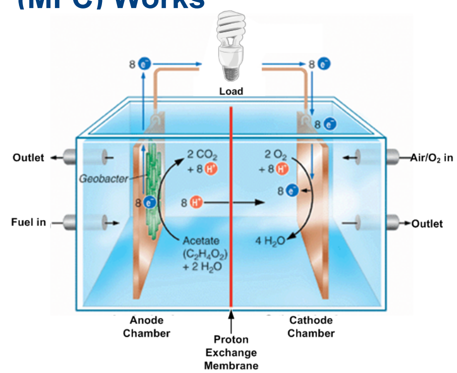
Kinetic Process	Equation Name	Formula	Category
1	Monod	$j = j_{\max} \frac{S}{K_{s,app} + S}$	Intracellular Potential Losses
2	Nernst-Monod	$j = j_{\max}\left(\frac{1}{1+\exp[-F/RT(E_{OM} - E_{KA}]}\right)$	
3	Ohm's Law	$j = -\frac{k_{bio}(E_{OM} - E_{Interface})}{\Delta Z}$	Extracellular Potential Losses
4	Butler-Volmer	$j = j_{\max}\left(\frac{1}{1+\exp[-F/RT(E_{OM} - E_{KA}]}\right)$	

- Microbial energy conversion limited by **intracellular and extracellular electron transport losses**
- **Combining structured biofilms** with **transport models** will allow better understanding of these losses

Objectives

•Engineer microbial communities with **deterministic charge and nutrient transport pathways**
•Characterize charge transfer using electrochemical modeling techniques to **optimize bio-electrochemical devices**

How a Microbial Fuel Cell (MFC) Works



- MFCs are well studied and have analogous transport mechanisms to other bio-electrochemical devices
- This makes MFCs an **ideal system to model**

MFC In Action

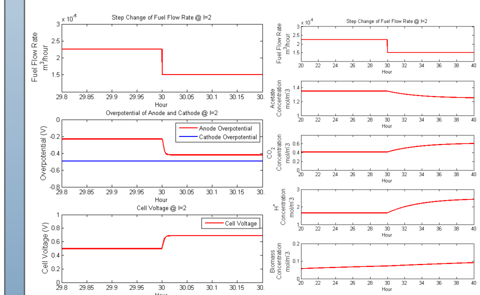
Anode reaction with acetate

$$(CH_2O)_2 + 2H_2O \rightarrow 2CO_2 + 8H^+ + 8e^-$$

Cathode reaction

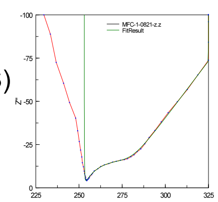
$$O_2 + 4e^- + 2H_2O \rightarrow 4OH^-$$

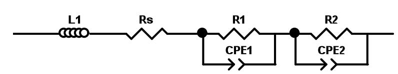
Modeling Mass Transport



Modeling Charge Transport

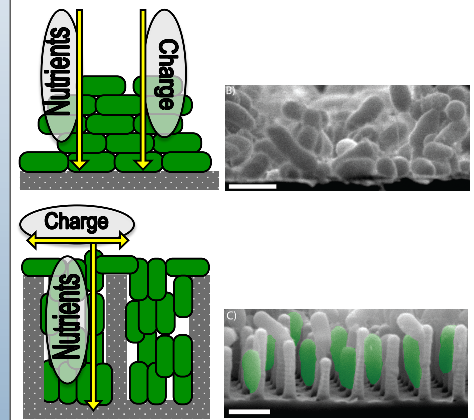
Electrochemical Impedance Spectroscopy (EIS) data fit by 2 RC equivalent circuit model with non-ideal capacitors





- **Dynamic simulations** allow comparison of mass transport model and experimental data.
- EIS provides **information on internal losses** in bioelectrochemical reactors.
- Model results from MFCs can be applied in other device configurations **to overcome transport limitations.**

Nanostructured Electrodes



•Charge and **nutrient transport are coupled in natural biofilms.**
•Nanostructured electrodes induce self-assembled biofilm morphologies that **decouple these transport length scales.**
•Feedback between model predictions and engineered biofilm structures **minimize internal losses**.
•Dual modeling-experiment approach will generate biofilm design principles to **maximize bioelectrochemical productivity.**

Future Applications

- Use bacteria **to store energy from solar and wind** in chemical biofuels

Acknowledgments

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